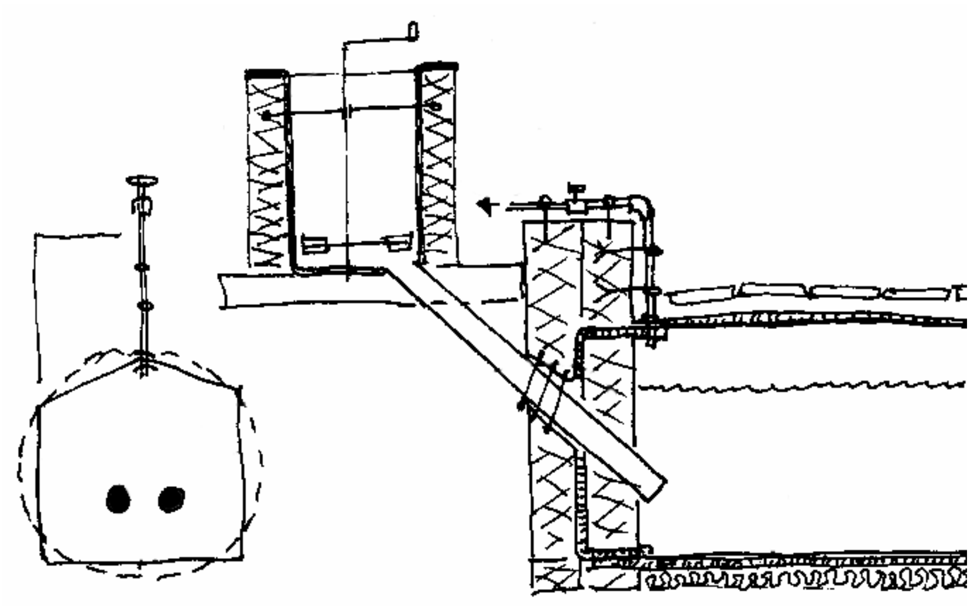
# Construction Options

# for RABR

# Remote Area Biogas Reactor

**Field Visit – May 2003**

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**Report date:** **Kathmandu, 08 June 2003**

# ABSTRACT

The successful dissemination of biogas technology in Nepal has been based on a single standard fixed-dome reactor design with a slurry outlet for hydraulic pressure. Because the reactor is built inside the ground from masonry and concrete, the working temperature remains stable. The large amount of building materials and cement makes it very expensive for remote areas. Remote areas in Nepal are all villages located more than one day's walk from the road head. The Remote Area Biogas Reactor (RABR) is an insulated bag reactor design which requires little cement and has low transport weight. Because most of the remote areas are also at high altitudes, the long bag reactor, being built into the ground, is thermally insulated to avoid cooling down during the night and in winter. The bag design is elongated for constructing on small terraces and can be extended to make reactors of different volume. The design is in a research and field testing phase.

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# List of Abbreviations

| | |
|---|---|
| BSP | Biogas Support Programme. |
| Dokha | Bamboo woven basket carried on the back, holds about 30 kg biomass. |
| EPS | Expanded Polystyrene. Light, white insulation material used in package industry. |
| EPE | Expanded Cellular Polyethylene Foam. Closed cells, expanded with LD PE resins. |
| HABR | High Altitude Biogas Reactor (over 1800m altitude). |
| HDP | High Density Polypropylene. Plastic used in water and sewerage piping. |
| HMG/N | His Majesty’s Government of Nepal. |
| LD | Low Density, terminology used in plastic industry. |
| NRs | Nepalese Rupees. One Euro = NRs 85 (at date of report). |
| PE | Polyethylene plastic with density 0.91–096. May be burned, non-poisonous. |
| PET | Polyethylene Terephthalate. Used for fully transparent water and soft drink bottles. |
| PP foam | Polypropylene foam. Commonly sold as under-carpet in Nepal, 5mm and thicker. |
| PVC | Poly Vinyl Chloride plastic with density 1.2 -1.55. Poisonous burning gasses. |
| RABR | Remote Area Biogas Reactor (more than one day’s walk from road head). |
| RMP | Red Mud PVC, red mud is a by-product of the aluminium industry. |
| UV | Ultra-violet. Short frequency solar radiation destroying binders in plastics. |

# 1. INTRODUCTION

This report is an elaboration on various issues raised in the "Mission Report of the High Altitude Biogas Reactor in the Khumbu Region, Nepal", dated October 2002. While this earlier report provides a diversity of information on research, firewood and analyses related to the Lukla/Mose biogas reactor, this present paper concentrates on providing details of a possible biogas reactor design for remote areas, including the High Altitude Biogas Reactor (HABR).

Only 9% of the population of Nepal (roughly 2 million) lives in the high mountain areas and this population is highly dependent on firewood for its energy needs (cooking, water and space heating). About 3 tons of firewood (100 Dokhas) are consumed per family per year at lower altitudes (up to 1500m), an amount which increases with altitude. Firewood consumption at the higher altitudes has an increased impact on deforestation as compared to the lower altitude of the Terai. That is because at the higher altitudes biomass is regenerated at a much slower pace than at lower altitudes. Due to this firewood consumption, forests at high altitudes are not exploited in a sustainable way.

In addition to the above, many Nepalese in the high altitude areas live in remote to very remote areas, meaning that it requires several days' walking to reach the villages. The direct effect is that all goods being brought from the lower regions to the remote villages become very expensive in either labour (walking/carrying) or purchase costs. The indirect effect is that these populations are largely subsistent and have a high dependency on local resources such as the forests.

With regard to biogas, it was observed that many smallholder farms have two buffalos to assist them in agricultural activities, such as tilling of the land and for milk supply. These buffaloes are mainly kept in stables and are considered an excellent source for biogas production. In some cases (Jersey) cattle was exclusively kept for the dairy products and stabled for long periods, especially during the winter.

Remote farms often have cattle for agricultural purpose and milk. Large quantities of firewood are needed for daily cooking. With a biogas reactor, firewood savings of about one ton per cow or water buffalo can be saved annually, as well as considerable time in firewood collection.

In the very high altitudes (over 3500m) villagers are keeping Yak, but during several months of the year these Yak are grazing in alpine fields. The suggestions in the present report do not yet cover these areas above 3500m.

The Nepalese biogas programme, developed with the support of many local experts and more than 50 construction companies, and with KfW, SNV/N and HMG/N subsidy support, has reached a phase in which it needs wider application and the largest possible range of farmers with cattle should have access to this Renewable Energy (RE) technology. The technology of the current fixed-dome design has reached maturity in construction quality, quality control, subsidy and management mechanisms, training and implementation in all easily accessible areas. This design, however, is not economic for remote areas.

The current Donor support to the national biogas programme, apart from the need to develop this RE resource, also has the obligation to address poverty alleviation issues. The remote people are usually the most economically disadvantaged people in Nepal and require special attention under all types of national development programmes to reduce the existing inequity between remote and non-remote people. Therefore, it is the remote smallholders and farmers with cattle who need to have access to this RE source which will reduce local forest degradation and improve sustainability of livelihood.

Terraces of farms in mountain areas are long and narrow. The design of biogas reactors should therefore fit into the available terrain without excessive digging into the terraces which may require the removal of large stone boulders or destabilising the ground structure.

## 1.1 REVISITING THE HABR IN MOSE/LUKLA

As a follow up to the earlier HABR report[1], the biogas reactor in Mose/Lukla was revisited. On the basis of this visit, the following observations and recommendations can be made which may prove useful for future developments. The observations are not meant to criticise the owner, but rather to illustrate typical problems that may occur with the given type of development.

### 1.1.1 Greenhouse Soil

For half of the year (from November to May), neither the house owner nor his wife utilized the greenhouse for growing crops, but rather used it as a workshop/atelier. The soil inside the greenhouse had not been improved and although a high local demand exists for vegetables[2], the family had no intention of using the greenhouse for producing and marketing vegetable products. Their only intent was to grow tomatoes and cucumbers for personal consumption.

The family seems to require training/information about crop production in greenhouses and its commercialisation. The marketing of excess produce would be essential for any new HABR, to offset the relatively high investment costs.

The growing of crops is related to soil and air temperature, water and nutrients. In the given case the soil inside the greenhouse was not enriched with nutrients or compost from the slurry. Although the air temperature was high (up to 20ºC), the ground temperature was still very low (2-5ºC). The ground temperature can only be improved if the topsoil layer is thermally well insulated from the underground.

In new greenhouse designs for high altitudes, the top planting soil needs to be enriched and thermally insulated from the underground. The better soil quality and higher soil temperature will produce an earlier plant growth.

### 1.1.2 Greenhouse Roofing

The owner requested BSP/SNV to replace the Silpaulin foil on the roof. The observation was that the current flat design (as explained in the earlier document) is defective and it would only be useful to assist the owner in replacing the Silpaulin UV-foil if the greenhouse design is modified into a round-shaped construction, demonstrating better material use. The owner showed little intention of making his own investments to maintain the construction. The greenhouse should be an economic activity, geared to generating additional benefits from using the slurry at these high altitudes. In this case there is neither educational support for the owner and his wife nor interest from their side to improve the situation at their own expense.

With the development of a new RABR or HABR design and in the application programme, an educational module on vegetable growing and marketing should be developed and implemented.

### 1.1.3 Toilet

The toilet attachment was still not completed. There seemed to be little intention of making any personal investment to realise the toilet attachment. A toilet used by two persons will contribute only minimally to the gas production, but good sanitation is a common problem in remote villages. A retention period of over two months considerably reduces eventual pathogens (80-90%) and further reduction will result with aerobic composting (50% of remaining pathogens). The overall result is considerably more sanitary than defecation in the open field, still being practiced in many locations.

A toilet attachment is highly recommended. To date no social or religious resistance (Buddhists) against the toilet attachment has been indicated in the Khumbu region.

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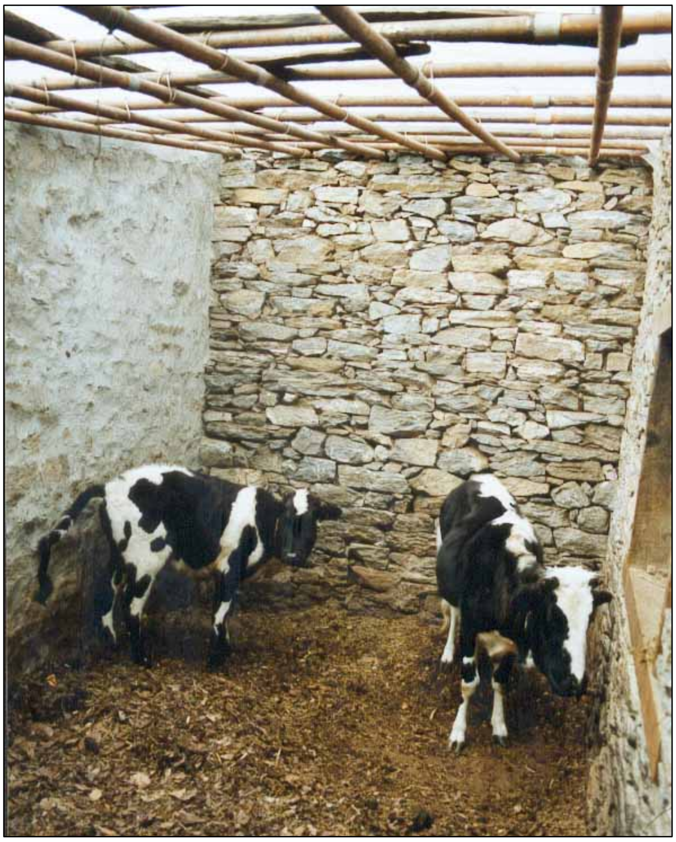
[1] Mission Report of the High Altitude Biogas Reactor in the Khumbu Region, Nepal, by Sjoerd Nienhuys and Willem Boers, dated October 2002.

[2] Local tea hoses and restaurants import fresh vegetable by plane because at such high altitudes certain crops can only be grown in greenhouses.

### 1.1.4 Cattle



Only two young cows were in the stable. The third, larger cow was in the field for off-farm grazing and is kept in the stable only from December to April. During these winter months the feeding of the reactor was probably up to its planned standard, but the gas production would not be optimised because there is a two-month retention period. During the warmer months from May to November, with the absence of the large cow, the reactor was underfed, producing insufficient gas. The survey form indicated the feeding, but data registration had been stopped in March 2003 when the large cow was moved out.

The owner/user of the biogas reactor must be able to do the registration himself/herself the entire year and not leave it to a third party to complete (as was the case here). With the new designs in the higher altitudes, good data collection can guide further improvements or adjustments. It is therefore important to only construct new RABR or HABR designs where the farmer himself/herself records and maintains reliable data.

### 1.1.5 Temperature Registration

The temperature inside the greenhouse and of the reactor content were both monitored during the winter period (October 2002 to March 2003). The registration showed a decline in the maximum greenhouse air temperature from approximately 20ºC to 15ºC in December and about 10ºC in January. The temperature inside the digester declined from about 10ºC in October to 1-0ºC in December and January, and 3-4ºC in March. Currently (May) the temperature was back to around 10ºC.

The first observation is that the reactor content (inside slurry) temperature has most probably the same temperature as the soil; not surprising considering contact and materials used. In future research of the new HABR, the external soil temperature outside the greenhouse needs to be monitored to assess temperature differences between the inside slurry and soil temperatures.

The second observation is that apparently the reactor still provides gas with a slurry content temperature of about 1-0ºC during November/December/January. Assuming that the temperature gauge hanging inside the slurry is accurate, this is important new data as it contradicts other research data suggesting that the production of methane gas will cease at these low temperatures[3].

Thirdly, it has been observed that the greenhouse does not function as an insulator of a dug-in reactor and has no influence on the temperature of the fixed-dome reactor. Warmed-up air inside the greenhouse has no effect at all on a construction inside the ground. The greenhouse may prevent loss of some warmth from the reactor, but in the fixed-dome design any possible warmth produced by the digester process is immediately absorbed into the mass of the walls and the surrounding ground. If a greenhouse has to make an impact on the reactor temperature, the content of the reactor should be very well insulated from the outside soil and have a small mass.

[3] The BSP programme should further assess this issue and publish the results.

#### 1.1.6 Gas Production

Average gas production or gas use was about one hour per day, with occasional use of one and half hours per day, measured during the past half year. The lady stops using the gas stove when the gas flame of the stove is becoming rapidly smaller. This is caused by low pressure and indicates that the gas reserve (height) inside the reactor is minimal.

A column "low flame" should be added to the registration form and the date recorded when the gas pressure becomes very low, indicating that the gas reserve in the dome has been consumed. With an improved registration form, a fair estimate can be made about gas consumption or production related to temperature and feeding.

#### 1.1.7 Gas Valve

The family has the practice of opening the main gas valve in the morning, leaving it open the whole day, and only closing it before retiring in the evening. This opening/closing practice was also observed in other biogas reactor owners in the Pokhara region.

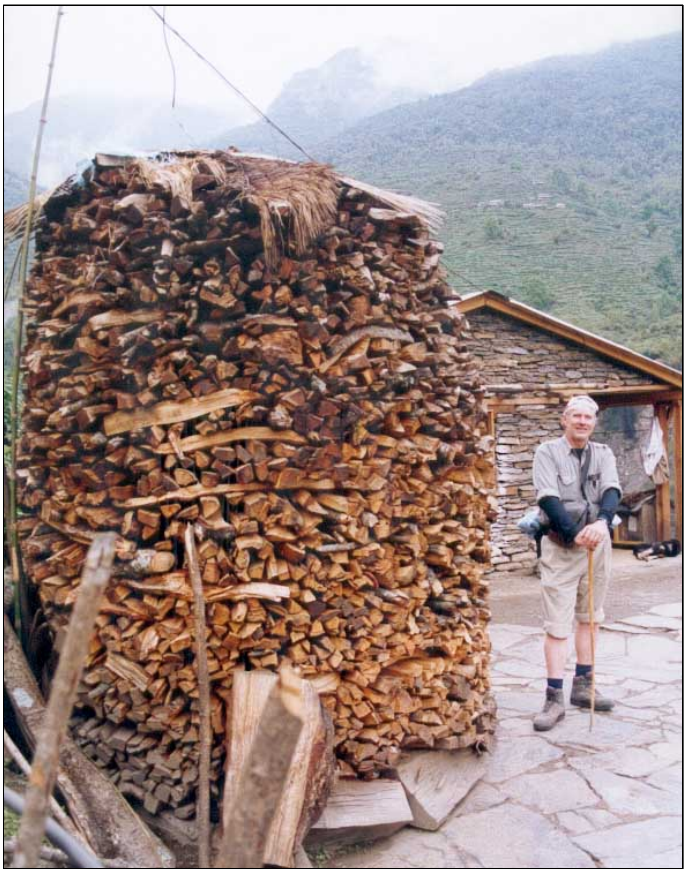
The quality of the main gas valve is as important as the gas stove shut-off valve.

#### 1.1.8 Firewood

The survey form does not provide information about firewood consumption. According to the farmer, he still uses 3 x 25 kg (three Dokhas) firewood per week during the summer and 5 x 25 kg firewood per week during the winter. In one year this is about 40 x 3 x 25 kg + 10 x 5 x 25 kg = 4250 kg firewood, thus drawing little benefit from the biogas and continuing local deforestation.

These vast amounts of firewood use are hard to believe (probably poor measurements or estimates), especially because it only concerns two persons on average.

A column for firewood consumption per week should be added to the registration form. In addition, the family needs to be provided with a scale.

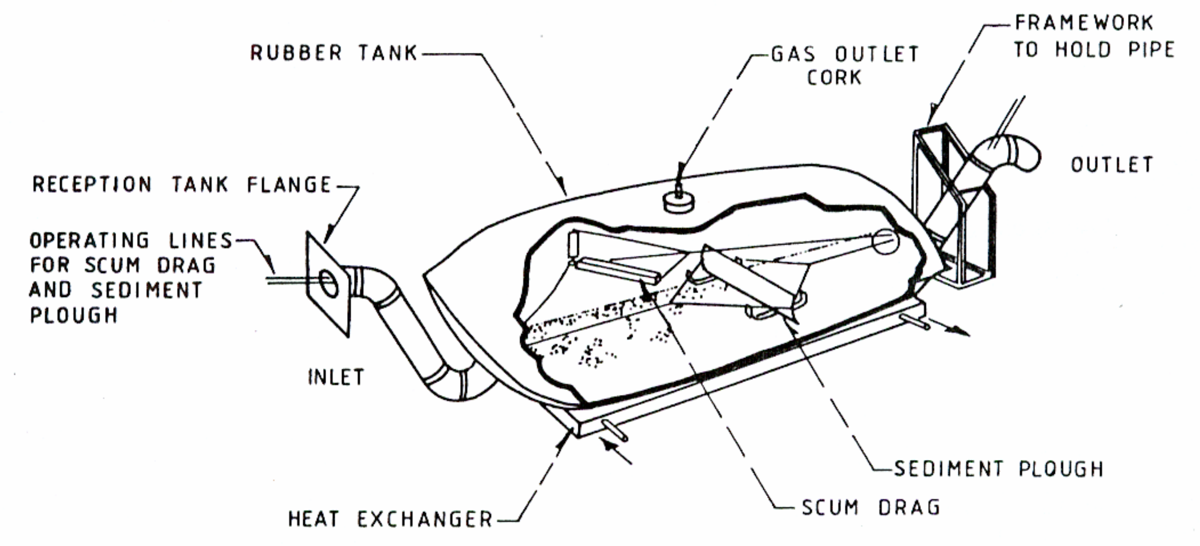


# 2. REMOTE AREA BIOGAS REACTOR

## 2.1 PREVIOUS RESEARCH

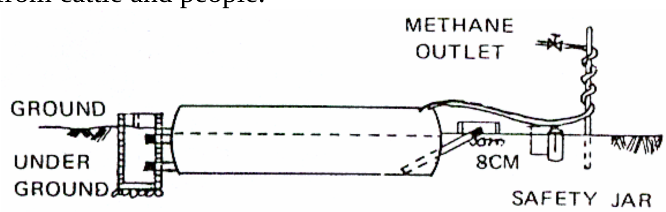
Based on previous experiences with low-cost and low-weight biogas reactors, the bag or balloon design biogas reactors are both low cost and low weight. In 1980 some options of bag designs were mentioned in the BIOGAS Newsletter, citing the possibility of easy transport and utilisation in high hill areas. Some designs were made of hylapon, neoprene or reinforced synthetic rubber.

In 1983 a rubber bag design of 2250 litres was mentioned[4]. This was a continuous plug-flow design and included a sediment plough, which is not required when only cattle or buffalo dung is fed into the reactor. The design used in several countries, but rubber bags are not easily available in Nepal.




The same issue of the BIOGAS Newsletter also mentioned the use of low-cost polymer, having a better resistance against UV light and environment than PVC[5]. A further improvement was the mixture of PVC with "red-mud", a by-product of the aluminium industry. At the time (1983) thousands of Red Mud PVC (RMP) digesters were in operation in South Asia, Brazil, and other countries for demonstration purposes. The digester was placed into a dug-out trench in the ground with the inlet and outlet made from masonry to maintain a fixed position.

In 1994 extensive experience was obtained in Columbia with the long rubber bag designs placed in a half deep trench inside large greenhouses[6]. This is called a "channel-type digester". The effect of the greenhouse was to warm the balloon and contain the heat. The greenhouse also provided mechanical protection for the bag from cattle and people.




(SIDE VIEW)

[4] Lockstocke Developments, Eastbourne Lane, Midhurst, Sussex GU29 9AZ, UK. BIOGAS Newsletter 18, 1983.
[5] RMP digester: UIRL, 1012 Kuand Fu Road, Hsinchu, Taiwan, Republic of China.
[6] Biodigestor Tipo Balon. Informativo Ambiental del Riseralda, Columbia. 20 Junio 1994.

Research in Nepal (November 1986)[7] included a PVC design being experimented:
"The design and construction may be easier and cheaper than floating drum 'gobar gas' plant. Bag is more appropriate to run engine compared to lighting which needs higher pressure. This is more easier to insulate with straw or hay or even compost during winter months. It is appropriate in hilly regions where transportation is the major problem. The pressure can be maintained with the help of four strings fixed at four corners which is a simple improvement in the design."

The cost of the above reactor was not significantly lower than the fixed-dome design for accessible sites (USD 170 in 1986). PVC is a poor quality bag material and needs replacement after a few years. Other research in Vietnam suggests that PVC bags are not very durable.

## 2.2 RECENT RESEARCH SUGGESTIONS

Resent research suggestions by BSP were based on the idea that the existing, well experienced fixed-dome design should be adhered to. This lead to the construction of two larger biogas reactors ($6m^3$) in Lukla/Mose and in Kumjung, both at a very high cost (NRs 150,000 - 200,000 with transport cost included). These amounts are unaffordable for local farmers (former HABR report on the Kumjung region refers) and too costly to subsidise on any scale.

The importance of keeping the proven, certified and controllable fixed-dome design as the basic design for all biogas reactors has its reasoning in the consolidated success of that design. The design is especially suitable for the Terai and lower Hill areas because it stabilises the inner reactor temperature, guaranteeing a steady gas production, whereas the construction is simple and robust.

A proposal was made to line the existing reactor design with the new Silpaulin material[8]. Although it was demonstrated in a scale model that this was technically feasible, and the construction could be made leak proof, doubt remained about how to make the dome construction with a lining of the same material. In realising the dome construction according to the fixed-dome design, care must be taken to ensure that the seam between the concrete foundation and the Silpaulin inner-lining is always under the maximum slurry level to avoid gas leakage.

Considering the cooling of the slurry in the digester inside the ground, the digester needs to be fully thermally insulated. Three options exist for the round digester tank and slurry outlet:

1. Insulation on the outside of the stone masoned round wall. This will require the minimum amount of stone masonry work. Wall thickness is usually 18". The outside wall will have the same temperature as the slurry, doubling the thermal mass of the reactor content.
2. Making a cavity wall and applying insulation in the 4" cavity. This will require considerable additional stonework for 2 x 18" walls, consisting in substantial work for the farmer to provide the stones. Also here the inner wall will have the same temperature as the slurry, doubling the thermal mass of the reactor content.
3. Applying the 4" thermal insulation on the inside of the wall. This requires slightly more stonework and needs a waterproofing layer between the slurry and the thermal insulation. Material containing air can be placed in large plastic bags and fitted against the inner side of the wall. The bags can be protected with thin Polypropylene foam (PP) before the Silpaulin liner bag is placed. In this way only the slurry content is the "warm" mass.

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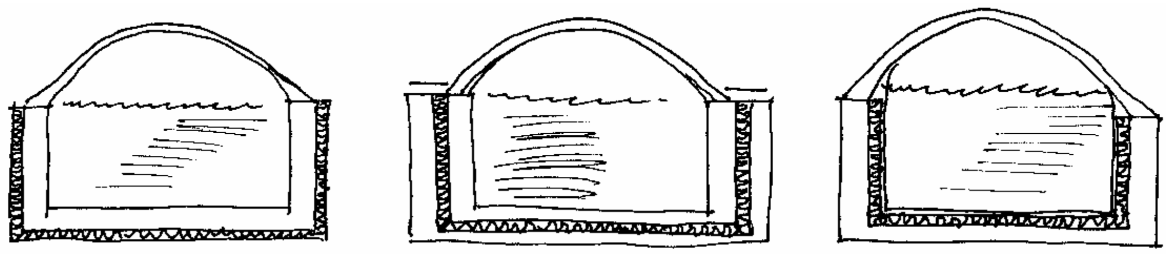
[7] Govinda Pradsad Devkota, Butwal. BIOGAS Newsletter 23, November 1986.

[8] Silpaulin is a brand name of an Indian manufactured multi-layered cross-laminated pond lining. The material has excellent tensile strength and comes in thickness of up to 250 $gr/m^2$. Thin greenhouse qualities of 120 $gr/m^2$ are highly resistant to UV light (+5 years) and thick coloured qualities for 20 years. It is fully resistant to sewerage and most chemicals, but has limited resistance to petroleum-based solvents. It is manufactured according to IS 146611-1998 and is available in Nepal.



Existing Fixed Dome
Smallest Amount of Stonework

Cavity Wall Design
Largest Amount of Stonework

Waterproof Insulation
Smallest Mass to Keep Warm

With the modified fixed-dome design proposal, the slurry outlet should be made long and narrow to allow the slurry channel to be covered with locally available slate slabs, rather than with reinforced concrete slabs. This will minimise the amount of concrete.

The modified fixed-dome reactor with a concrete dome design still requires more than 8 bags of cement[9] or NRs 24,000 for cement alone. Further attempts to make the fixed-dome design lighter or cheaper are not considered economically feasible for the following reasons:

- Cement is becoming more and more expensive with the number of walking days from the road head. About NRs 500 per day for transport.
- Skilled craftsmen who know how to use the cement correctly and make good quality concrete are often not available in remote areas. Skilled craftsmen need to be imported from lower areas.
- Good quality concrete requires clean sand which is only available in the wider riverbeds where sedimentation has occurred in slow moving water. Such rivers exist only in low altitudes, hence incurring again high transport costs.
- Good quality aggregate for concrete needs to be manufactured on site, involving intensive labour. Also if the farmer makes the aggregate, it is still a lot of work.
- Concrete designs have a large mass demanding large amounts of heating-up energy from the digester slurry. During winter the stone mass will require additional energy if the thermal insulation is not applied on the inner side.
- The round shape of the dome is difficult to make gastight.
- The round shape of the fixed-dome design and the square shape of the slurry outlet are a logic design in concrete or masonry, but are not practical with a plastic lining.

A scale model (1:4) was manufactured in cardboard to clarify the construction sequence and to serve as a guideline for an eventual self-help manufacturing manual. Half way the production of this model the activity was stopped because no convincing solution was defined for the thermal insulation of the bottom of the digester tank (roughly 50% of the digester surface in contact with the slurry). Making the digester or the outlet with only half of the surface insulated would not be useful because all heat loss will occur through the non-insulated floor area, rendering the insulation of the walls useless.

Based on the above observations the SREA abandoned the idea to try to match a new design shape with the fixed-dome design.

[9] The cost price per 50 kg bag of cement at the road head is about NRs 400. With one day carrying, NRs 900; with two days carrying, NRs 1500; with three days carrying, NRs 2000; with four days carrying, NRs 2500, with five days carrying, NRs 3000.

# 3. NEW RESEARCH AND APPLICATION

Based on the former HABR report, past research and the findings of the recent field visit, it is suggested to restudy the applicability of the bag digester design again, mainly because of its low weight and easy transportability.

The second reason why the bag digester design should be restudied is the fact that new plastic materials, which are more resistant and durable than the PVC foils, have become available in the local market. The selected material for the bag design is Silpaulin[10], which can be factory welded into long gastight tubes.

## 3.1 CHARACTERISTICS OF RABR

To deliver a biogas reactor to remote areas substantial changes need to be made to the current fixed-dome design or a totally new design needs to be developed:

- The amount of cement and/or concrete needs to be drastically reduced (currently more than 14 bags). Concrete requires good quality sand, often only available from riverbeds.
- The design should be rather shallow and narrow so it can be constructed in the long terraces. Digging out of large stone boulders needs to be avoided.
- The dimensions of the components should not exceed 2 meters to allow easy transportation. The trekking routes are often very narrow, limiting the manoeuvrability of long pieces.
- The weight of the unit components should not exceed 50 kg to allow easy transportation. The maximum carrying capacity of porters lies around 70 kg for altitudes up to 3000m.
- The design should be realised locally by local craftsmen who have received training.
- The cost should be recoverable in a few years, considering labour and fuel(wood) expenses.
- The attachment of a toilet is highly recommended for sanitation purposes.
- Water storage is recommended inside the greenhouse, allowing pre-warming.
- Planting soil inside the greenhouse should be thermally insulated from the soil below.
- Any bag design (channel-type digester placed into an elongated trench in the ground) should be fully protected from UV light and against mechanical damage.
- Greenhouse foil should be strapped in a round-shaped frame to eliminate flapping in the wind.

## 3.2 CHARACTERISTICSOF HABR

Not all RABR will be above the 1800m, but those that are have some additional requirements that will make the installation a HABR.

- The HABR design should be well insulated from the soil for altitudes over 1800m.
- The design should have an all-covering greenhouse construction over the digester and outlet.
- Cattle should preferably be housed inside the greenhouse.
- Education on crop production should be provided to the farmer.
- For altitudes over 2500m water pre-heating by SWH inside the greenhouse is recommended.
- For altitudes over 3000m thermal insulation curtains are needed, depending on the type of crops the farmer wants to grow during the winter or early spring.
- Greenhouse foil should be protected from falling ice or snow (from roofs).

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[10] Silpaulin is commonly used for greenhouses (translucent 120 gr/m$^2$) or for pond lining (blue 200-250 gr/m$^2$). It can be factory sealed and welded. With given dimensions the exact shape can be pre-manufactured and transported to the site, ready to install. This will minimise the amount of work needed on the site.

## 3.3 TECHNICAL DESCRIPTION

The overall design is a continuous plug-flow design, allowing construction in shallow and long locations, such as mountain terraces. The shallow depth avoids the need to remove large stone boulders that inevitably are part of the terrace structure in the mountains.

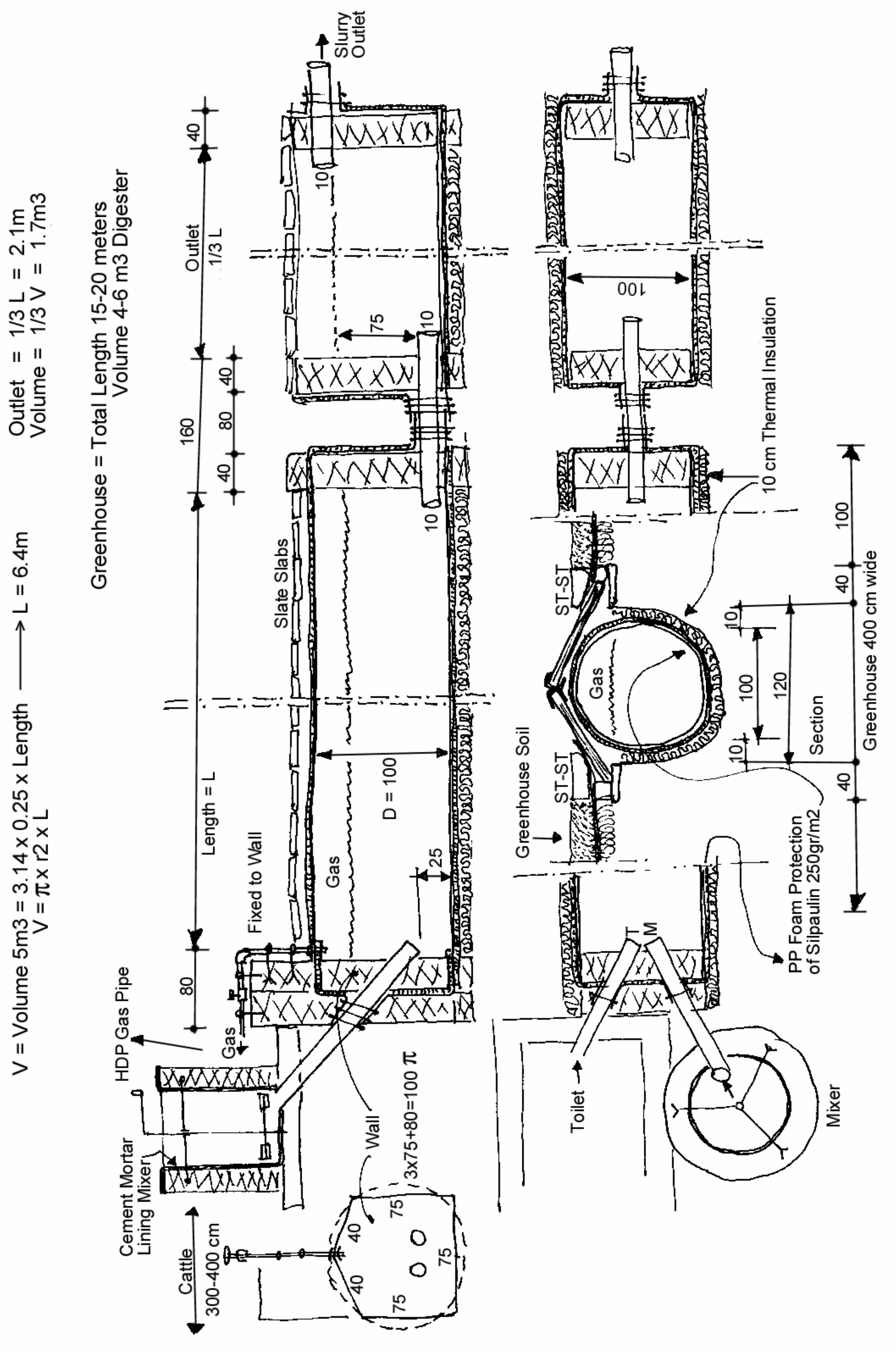
The slurry outlet is one-third the length of the digester, providing sufficient volume to allow the slurry to move back into the digester with the gas consumption. The construction should have on the mixer side sufficient room for cattle or the greenhouse should be connected immediately to the cattle shed. The toilet construction can provide stabilisation of the greenhouse and separation between the digester and cattle area. The masonry of the toilet cabin is not included in the calculations. The compost pits are outside the greenhouse.

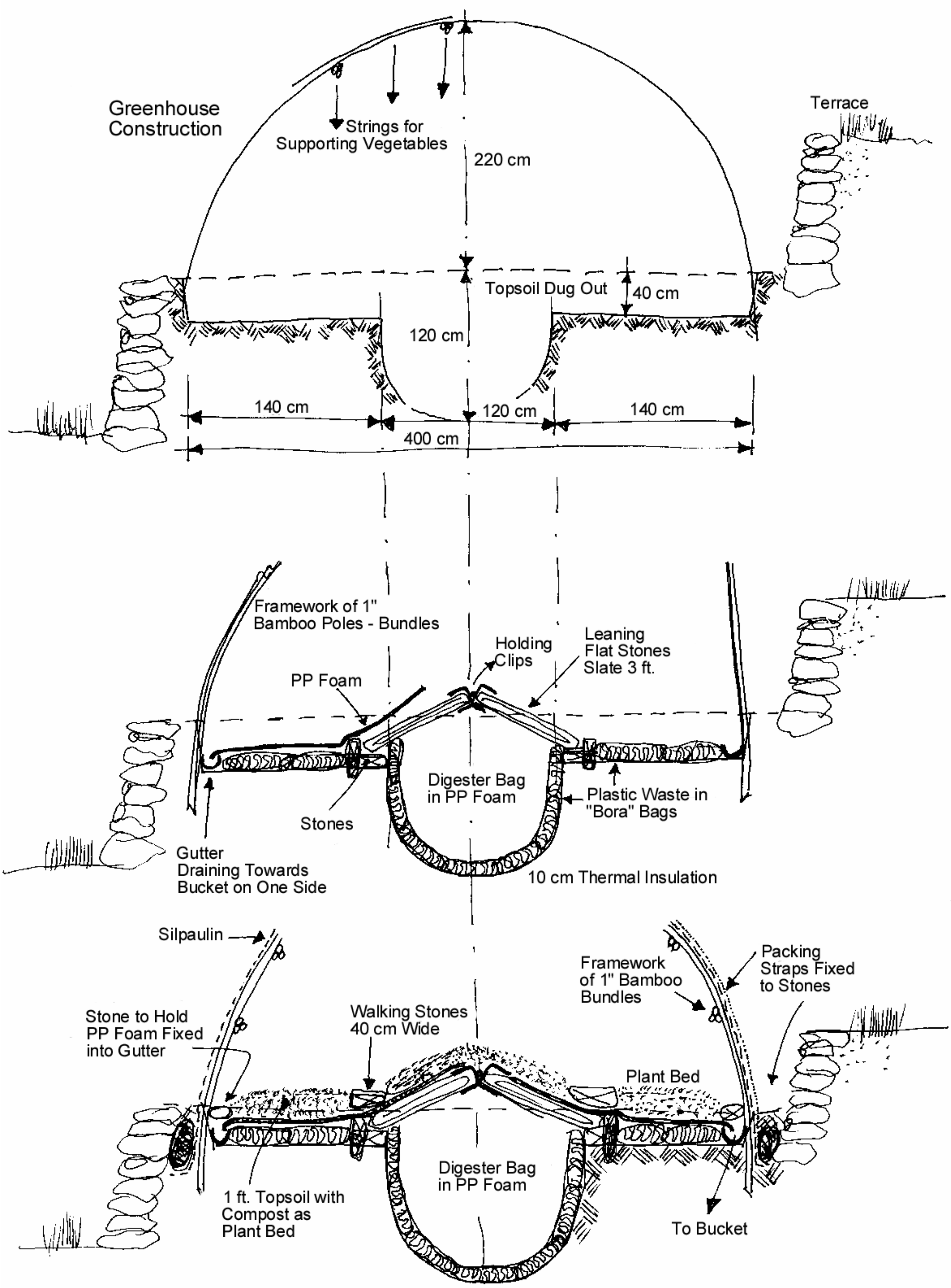
The 10cm thermal insulation material can be made from plastic waste material, such as empty PET bottles and other (non-sharp) plastic waste (PVC bags) stuffed into PP fibre agricultural sacks (*bora* in Nepali). Alternatively agricultural waste material can be used, being stuffed into PVC bags to keep it dry. The agricultural waste should not become wet and care taken to avoid this.

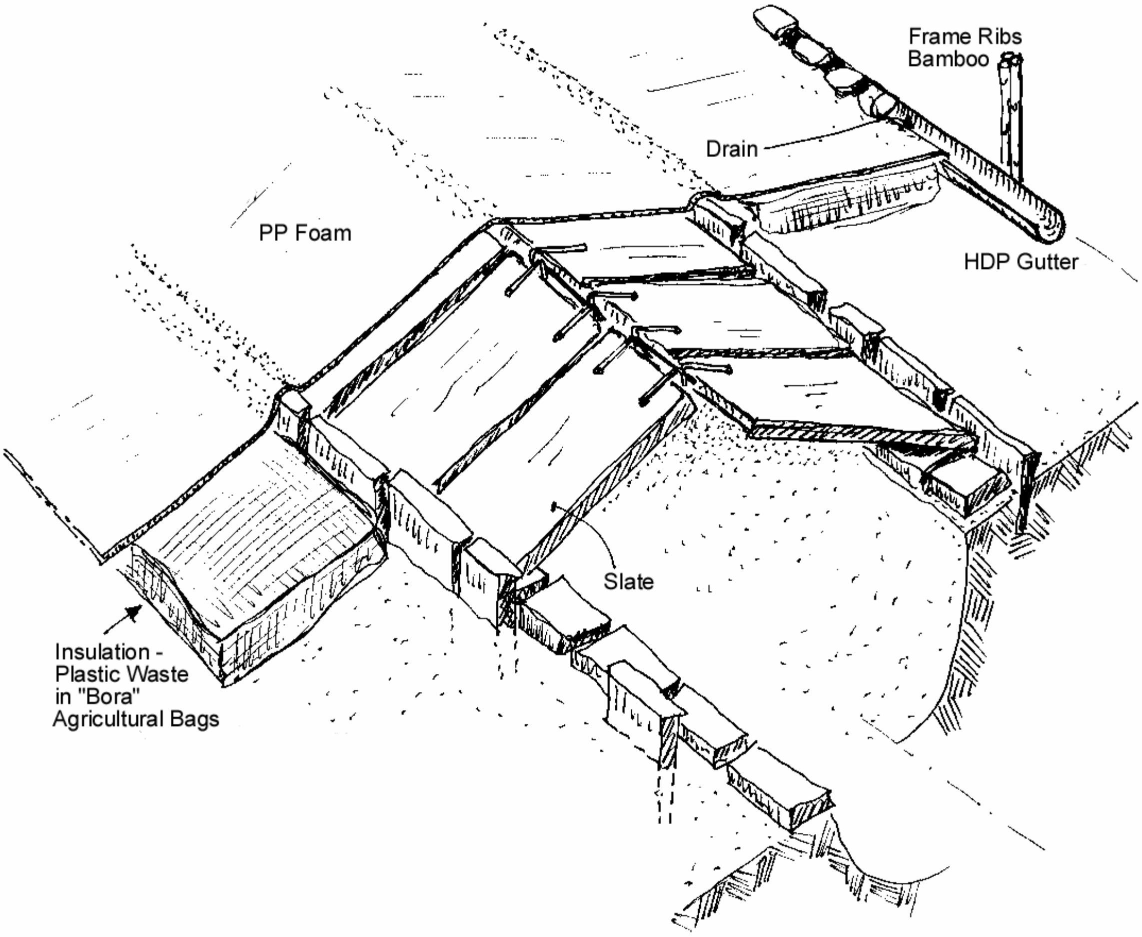
- The greenhouse fits on most terraces in mountain areas. Minimum 4m wide x 10m long.
- Silpaulin for digester and outlet bags is $41m^2$ x 250 $gr/m^2$ = 10.25 kg for the $5m^3$ digester. Cost price: 450 sq. ft. @ NRs 14 = NRs 6300.
- The 5mm PP foam[11] has a surface of $40m^2$. At 180 $gr/m^2$ about 7 kg. Cost price @ NRs $60/m^2$ = NRs 2400.
- Silpaulin for the greenhouse is $80m^2$ x 120 $gr/m^2$ = 10 kg. Cost price: 880 sq. ft. @ NRs 7 = NRs 6160.
- The HDP 4" pipes (4 $kg/cm^2$) for the connections between mixer, toilet and between the units is about 6 kg. Length 6m. Cost: NRs 500.
- One bag of cement (50 kg @ NRs 400 at road head) may be sufficient to plaster the inside of the mixer and the toilet floor. Cost: NRs 1500.
- The greenhouse frame structure is made from 1" bamboo sticks, bent in shape and bundled to obtain sufficient strength.
- Total transport cost of 150 kg, about NRs 10/kg/day or one day walk is NRs 1500; two days' walk is NRs 3000 and three days' walk NRs 4500.
- Total cost of imported materials as per cost price in the city NRs. 20,000. Additional are the local material costs (bamboo, stone) and labour.

| | | |
|---|---|---|
| 1 | Length of Digester of 5m3 | 640 cm |
| 2 | Length of Outlet of 1.7m3 | 210 cm |
| 3 | Width of Digester and Outlet | 100 cm |
| 4 | Width of excavation trench | 120 cm |
| 5 | Hydraulic height gas pressure | 75 cm |
| 6 | Total construction height Digester | 130 cm |
| 7 | Gas pipe to farmhouse HDP | 1.2 cm |
| 8 | Non-masoned stone walls constr. | 40 cm |
| 9 | Covering with slates, thick 1" | 90 cm |
| 10 | Overall length reactor | 850 cm |
| 11 | Overall length greenhouse | 1000 cm |
| 15 | Cattle shed and toilet area not incl. | (500 cm) |
| 16 | Greenhouse width | 400 cm |
| 17 | Height of greenhouse inside | 220 cm |
| 18 | Silpaulin PP surface reactor 5m3 | 28 m2 |
| 19 | Silpaulin PP surface outlet 1.7m3 | 13 m2 |
| 20 | HDP pipes 4"=10cm inlet/outlet | 6 m |
| 21 | Stone masonry 40 cm wide | 10 m2 |
| 22 | Cement for mixer + toilet floor | 1 bag |
| 23 | Total Silpaulin greenhouse | 80 m2 |
| 24 | Total weight of imported materials including bag of cement, mixer, HDP pipes, gas pipes, string, Silpaulin, PP foam, stove, etc. | 150 kg |

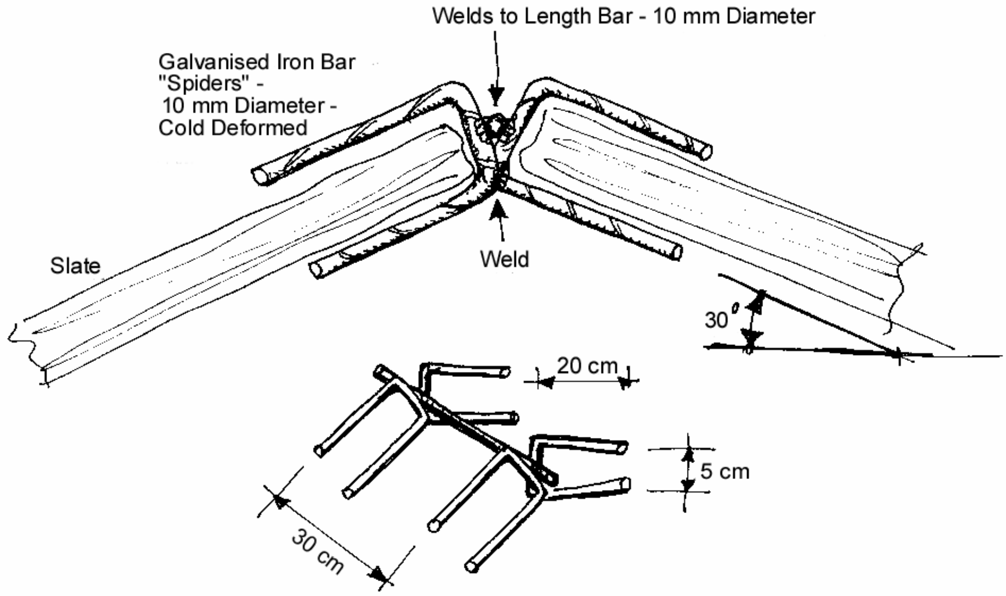
[11] PP is expanded cellular Polyethylene foam, usually used as under-carpet and by some trekking agents as insulating mattresses. The 5mm thin foam layer will protect the Silpaulin against damage from the thermal insulation material. The PP foam consists of multiple small, sealed cells that do not allow water absorption.


V = Volume 5m3 = 3.14 x 0.25 x Length ——→ L = 6.4m
V = π x r2 x L
Outlet = 1/3 L = 2.1m
Volume = 1/3 V = 1.7m3
Greenhouse = Total Length 15-20 meters
Volume 4-6 m3 Digester
Slurry Outlet
Outlet 1/3 L
160
40
80
40
75
10
Length = L
Slate Slabs
Fixed to Wall
Gas
D = 100
25
HDP Gas Pipe
Gas
Cement Mortar Lining Mixer
Cattle 300-400 cm
Wall
3x75+80=100 π
75
40
100
10 cm Thermal Insulation
ST-ST
Greenhouse Soil
Section
120
Greenhouse 400 cm wide
PP Foam Protection of Silpaulin 250gr/m2
T
M
Toilet
Mixer


Greenhouse Construction
Strings for Supporting Vegetables
220 cm
Terrace
Topsoil Dug Out
40 cm
120 cm
140 cm
120 cm
140 cm
400 cm
Framework of 1" Bamboo Poles - Bundles
Holding Clips
Leaning Flat Stones Slate 3 ft.
PP Foam
Digester Bag in PP Foam
Plastic Waste in "Bora" Bags
Stones
Gutter Draining Towards Bucket on One Side
10 cm Thermal Insulation
Silpaulin
Framework of 1" Bamboo Bundles
Packing Straps Fixed to Stones
Stone to Hold PP Foam Fixed into Gutter
Walking Stones 40 cm Wide
Plant Bed
Digester Bag in PP Foam
1 ft. Topsoil with Compost as Plant Bed
To Bucket



Frame Ribs
Bamboo
Drain
PP Foam
HDP Gutter
Slate
Insulation -
Plastic Waste
in "Bora"
Agricultural Bags

Welds to Length Bar - 10 mm Diameter
Galvanised Iron Bar
"Spiders" -
10 mm Diameter -
Cold Deformed
Slate
Weld
30°
20 cm
5 cm
30 cm

## 3.4 RECOMMENDED DESIGN MATRIX

The following design options are currently considered for the respective altitudes. One of the most relevant changes as compared to the former HABR report is the recommendation to have a greenhouse at ALL altitudes over 2000m (6000 ft.) because the greenhouse will provide:

- An improved (warmer, light) environment for the cattle.
- Supplementary fodder for the winter season for the cattle, improving biogas production.
- Improved food supply for the farmer's family and marketing excess food production.

Both the digester and the outlet need to be insulated from the soil. Insulating only the digester will allow the slurry outlet to cool down to ground temperature (0ºC in winter). The backflow from the outlet (resulting from gas consumption) will then bring the cooled down slurry back into the digester and undo any possible effect of the thermal insulation of the digester.

| Altitude Range with about Eight Hours of Daily Sunshine from the South | Altitude Range with about Four Hours of Daily Sunshine from the South | Construction of Biogas Reactor Design in the Ground | Construction of Greenhouse, Oriented to the Sun Needed |
|---|---|---|---|
| 3300m – 4000m<br>11,000 ft. – 13,000 ft. | 2800m – 3300m<br>9,000 ft. – 11,000 ft. | Thermal insulation reactor and greenhouse essential.<br>PP foam to protect Silpaulin bags.<br>SWH with heat exchanger for mixing warm water inside greenhouse. | Insulated greenhouse soil floor for storage of thermal energy.<br>Built against main farm building inside which cowshed.<br>Night curtain depending on type of crop production and period. |
| 2800m – 3300m<br>9,000 ft. – 11,000 ft. | 2300m –2800m<br>7,500 ft. – 9,000 ft. | Thermal insulation and greenhouse essential.<br>PP foam to protect Silpaulin bags.<br>Warm water storage in greenhouse. | Insulated greenhouse soil floor for storage thermal energy.<br>Built against main farm building.<br>Night curtain recommended depending on type of crop/period |
| 2300m – 2800m<br>7,500 ft. – 9,000 ft. | 1800m - 2300m<br>6,000 ft. – 7,500 ft. | Thermal insulation and greenhouse essential.<br>PP foam to protect Silpaulin bags.<br>Water storage in greenhouse. | Insulated greenhouse soil floor important. Attached to cowshed recommended.<br>Good ventilation, easy to regulate. |
| 1800m – 2300m<br>6,000 ft. – 7,500 ft. | 1500m – 1800m<br>5,000 ft. – 6,000 ft. | Thermal insulation and greenhouse essential.<br>PP foam to protect Silpaulin bags.<br>Warm water in winter period. | Preferably an elevated and insulated greenhouse soil floor.<br>Good ventilation, easy to regulate needed for summer. |
| 1500m – 1800m<br>5,000 ft. – 6,000 ft. | 1200m – 1500m<br>4,000 ft. – 5,000 ft. | Thermal insulation and greenhouse essential.<br>PP foam to protect Silpaulin bags. | Greenhouse recommended for better food production.<br>Good and easy ventilation for the summer essential to cool down. |
| Up to 1500m<br>Up to 5,000 ft. | Up to 1200m<br>Up to 4,000 ft. | Standard design, thermal insulation not really essential but beneficial.<br>PP foam to protect Silpaulin bags is essential. | Greenhouse not essential.<br>For farmers who desire to produce special crops off-season, the greenhouse may/can be commercially interesting. |

Night curtains can be placed in the greenhouse, depending on the type of crops and the season in which they crop grow. The night curtain is recommended in all cold and strong wind areas.

When possible greenhouse should be shielded from strong winds. This will enhance the durability of the greenhouse foil.

For details about the greenhouse construction, including the greenhouse for HABR, see the report entitled: "Construction Options for Greenhouses in High Altitude Areas", June 2003.

# 4. RABR CONSTRUCTION SEQUENCE

The sequence of the RABR and greenhouse construction is as follows:

A. Select a fairly straight terrace where the cattle shed, biogas digester, slurry outlet and compost pits can be placed one behind the other. Minimum length of a $4m^3$ digester with mixer and slurry tank inside the greenhouse (without the cattle shed) is about 10 meters.
B. The minimum width of the land section should be 5 meters, being 4 meters for the greenhouse and some area alongside for walking and digging in the UV foil. The terrace width should allow sufficient stability after digging out the trench for the digester and slurry outlet.
C. The topsoil is dug out 40cm deep and kept separate. The topsoil needs to be mixed at a later stage with compost to provide planting bed material.
D. A central channel is dug out for another 80cm for the entire length of the digester and slurry outlet. This can be done with the assistance of a template, having the half round shape of the digester including the insulation thickness.
E. The bamboo stakes of the greenhouse bows are then placed vertically and deep inside the soil along the sides of the 40cm excavation. Conservation against rotting of the bamboo section in the soil is highly recommended to enhance durability. In some constructions ½" GI water pipes are hammered into the ground and the bamboo sticks placed on the ground and attached with string. The GI water pipes are costly in purchase and transport.
F. Along the side of the trench excavation flat stones are placed to form the bottom and side support for the larger inclined flat stones that will cover the digester. The upright stones need to be well fitted inside the ground to withstand horizontal forces.
G. (not essential but recommended) Along the outside of the greenhouse a half size 4" HDP pipe can be laid for capturing excess water from the plant bed.
H. The space between the support stones along the digester trench and the outside is filled with 10cm (4") plastic waste stuffed into fibre bags (*bora*). Also the inside of the digester and slurry trench need to be lined with 10cm thermal insulation. The plastic waste can consist of empty plastic PET bottles and crumbled-up packaging material. Preferably no organically degradable material should be used unless it can be assured that the bags containing this organic material are watertight and the contents remain dry.
I. Inside the two trenches the PP foam lining is placed and then the Silpaulin tubes (250 $gr/m^2$). The gas outlet pipe is tightly fitted to the top of the Silpaulin bag on the mixer side and held temporarily in place by a frame made from wooden sticks.
J. The masonry work inside the tube endings with the connection of the HDP pipes is realised and the Silpaulin foil is connected (waterproof) to the HDP pipes with duck tape. The stone masonry is completed and the gas outlet pipe permanently fixed in the head walls, next to the mixer.
K. Complete the mixer construction and eventually the toilet. The toilet is recommended.
L. The 2½ ft. long flat stones are placed as roofing over the digester bag with the aid of galvanized holding clips called “spiders”. Ensure that the feet of the stones do not slip sideways.
M. Over the roof stones and their footstones a PP foam sheet will then be placed to prevent soil from entering in between the roofing slates. This will allow planting soil to be placed on the PP foam.
N. (recommended) Over the horizontal thermal insulation another PP foam is placed (or the former extended), draining towards the gutter. This sheet will allow draining of excess water sideways towards the half HDP gutter. The PP foam needs to enter the side gutters.
O. (recommended) To hold the PP foam in location, small stones can be laid on top of the gutters and large (40cm wide) stepping stoned placed over the footstones holding the roof slates. From this line (path) of stepping stones, the farmer can reach the central part over the roof stones, as well as the sides of the greenhouse for tending the vegetables. Making the greenhouse wider than 4 meters will require an additional walking path.
P. (not essential) At the ends of the side gutters a bucket can be placed to capture eventual drainage water, as well as condensation water from the inside of the Silpaulin. After fitting of the Silpaulin (120 $gr/m^2$, clear) the foil needs to be pressed to the outside of the gutter.
Q. The bamboo framework is made to sufficient strength to withstand locally known wind forces and to support large amounts of vegetable growth hanging from the ribs and girders.

R. The Silpaulin is placed over the bamboo frame and tied into the ground.
S. Packing belt straps are placed over all the girders in between the ribs to hold the foil down.
T. Doors are placed on each end of the greenhouse to allow ventilation (install thermometer).

As a result of the geological formation of the Himalayas, there are a large number of areas where slate has been formed and several of these areas have become mining areas for the local population. The high quality of this slate allows flat stones of 2-3 ft. long and 1-2 ft. wide, with a thickness of only 1" to 1½" (see photo below). These stones are perfect for covering the biogas digester bag, provided the footing is sufficiently stable to avoid sideways sliding. The minimum suggested placement angle of the stones in a tent-shaped roof over the digester bags is 30 degrees, although lower is technically possible with solid footing. With 30 degrees, the height of the centre ridge is four times the width of the span. To keep the flat stones together at the ridge, a "spider" grip is required, made from 10mm cold deformed steel reinforcement bar, welded and galvanised. The flat stones need to overlap half the width, while each "spider" can grip three or four stones. The legs of the "spider" can be closed slightly with a hammer to adjust to the thickness of the stones. It is estimated that one spider is required for every 50cm length of digester bag or slurry outlet.

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